Evaluation of S-band radar rain rate retrieval algorithms and precipitation variability over a dense rain gauge network

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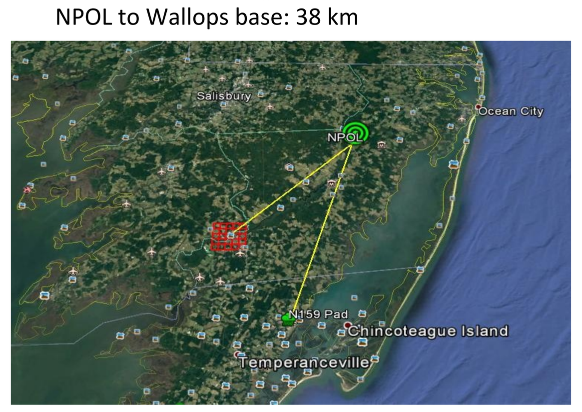
1. Introduction

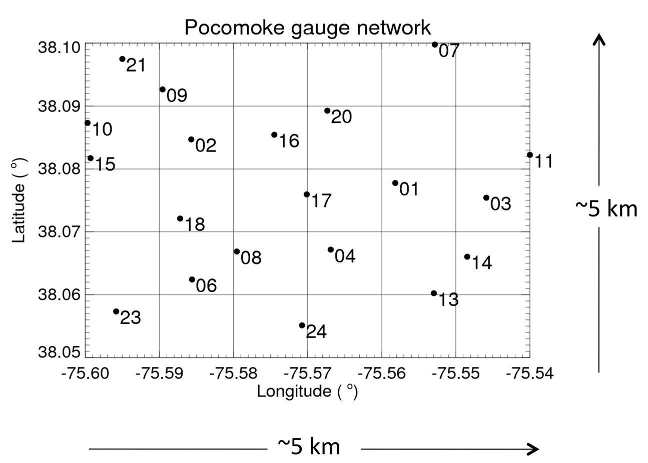
The Global Precipitation Measurement (GPM) Precipitation Research Facility (PRF) at NASA Wallops Flight Facility has recorded high temporal (50 second) and spatial (250 m) resolution PPI radar data over a dense rain gauge network using NASA's research-quality NPOL (S-band, dual-polarization) radar. The rain gauge network contains 20 tipping bucket gauge pairs distributed through an approximate 25 km^2 grid located 30km from the NPOL site. Precipitation rates derived from three polarimetric retrieval algorithms (in polar space) were interpolated to a 1.0 km horizontal resolution grid directly over the gauge network. Rain accumulation bias and Mean Absolute Difference statistics from the polarimetric retrievals and the non-polarimetric Multi-Radar/ Multi-Sensor (MRMS) System gauge-adjusted Z-R retrieval (at native resolution of approx. 1km x 1km) were determined via independent gauge comparison from four cases individually and collectively. **The analysis investigates how the statistics from the polarimetric and MRMS retrievals vary from event-to-event and in total over 6, 10, and 14 minute accumulation windows, and if there is a preferred retrieval most appropriate for a specific event type.** In addition, the dimensions of the dense gauge network were intentionally set to be nearly identical to the GPM Dual-frequency Precipitation Radar (DPR) nadir footprint-scale of 25 km^2. **The rainfall accumulations within the sub-grid scale footprint indicate variability from 100% - 400% depending on event – this is a significant contributor to error within the comparison method.**

2. Instrument / data descriptions and locations

NPOL Characteristics for this study	
Frequency	2.8 GHz
Pulse Repetition Frequency (PRF)	1100 Hz
Wavelength	10.67 cm
Gate Spacing	250 m
Beam Width	0.95 deg (H and V)
Processor	Sigmet RVP-9 / RCP-8

NPOL to Pocomoke gauges: 30 km
NPOL to Wallops base: 38 km

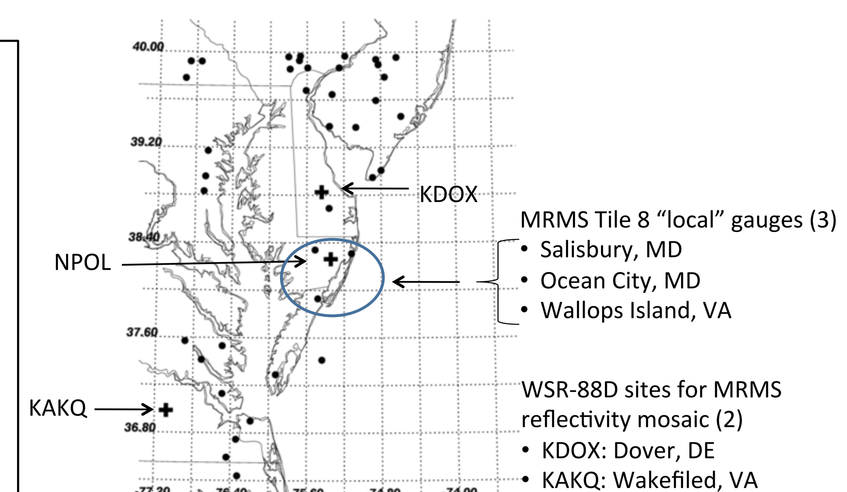




Data descriptions:
*NPOL "Rapid-Scan": 50-second resolution sector PPI; 1.2 deg elev; Gridded to 1 km H-resolution; Pseudo-CAPPI centered on beam.

*MRMS: Tile 8 RQI–filtered and Gauge-adjusted rates with 2-minute resolution; 0.01 deg grid spacing in latitude and longitude. Comparisons using MRMS are being done at the native MRMS resolution (approx 1km x 1km grid spacing).

*Gauge: Met-One tipping bucket; 0.254 mm per tip; 1-second resolution 20 collocated gauge *pairs* (40 gauges total) in the Pocomoke grid prior to quality control. Only "A" or "B" gauges are selected for each case (20 gauges prior to QC).



3. Rain rate estimation algorithms

RR ("DROPS2.0" Chen et al. 2017)
- Incorporates a dual-pol QC algorithm and Kdp estimation.
- "Region-based" hydrometeor ID instead of bin-by-bin.
- Includes RUC model sounding vertical temp profile as input.
- Rain rate relation equations based on DSD observations from 14 APU disdrometers employed in NASA's IFloodS field campaign (Iowa 2013).
- Architecture of DROPS2.0 is similar to Cifelli et al. 2011

RC (Cifelli et al. 2003, 2011)
- Polarimetric optimization algorithm driven by hydrometeor ID (HID).
- Our application in this study does not consider mix or ice – only rain.
- Rain rate estimation equations: [R(Zh), R(Zh,Zdr), R(Kdp, Zdr), R(Kdp)] using pol-variable thresholds.
- Pol equations physically based – derived from range of gamma DSD parameters typically found in observations (simulated obs).
- Assumes drop shape following Beard and Chuang (1987) equilibrium model.

RP (Bringi et al. 2004):
- Z-R relation of the form $Z = aR^{1.5}$
- Coefficient "a" continuously adjusted as DSD evolves in space/time.
- Normalized gamma DSD parameters estimated via radar measurements of Zh, Zdr, and Kdp (via Gorgucci et al. 2002)
- Method continuously estimates DSD parameters
  - no classification of rain type is needed.

MRMS (Zhang et al. 2011, 2016):
- WSR-88D Reflectivity mosaic (3D) with exponential weighting function based on distance and height.
- DP Quality Control + VPR + RQI (based on blockage and beam height).
- Radar-based QPE (R-Z) using automated sfc precip classification + NWP model data
- NOAA Hydrometeorological Automated Data System (HADS) gauges
- Radar-based QPE can be modified via local gauge bias correction (inverse – distance-weighted).

4. Case descriptions and comparison results

Cases (all from 2015)	Event Description	NPOL data	# gauges for NPOL	# gauges for MRMS
June 2	Moderate strat w/conv	2.5 hours	18	11
	Light stratiform	1.5 hours		
June 21 (TS Bill)	Strong conv	1 hour	18	9
	Mod / Heavy strat	6.5 hours		
June 24	Light/mod strat w/minor conv coverage	3.5 hours	18	9
June 26	Strong conv w/ mod strat	1 hours	18	10
	Light/mod strat	5 hour		

Accumulations from all estimates are evaluated over 3 time windows (6, 10, and 14 minutes).
Bias = (Σ Radar – Σ Gauge) / Σ Gauge X 100.
Mean Absolute Difference (MAD) = <|Radar – Gauge|> / <Gauge> X 100.
R = correlation coefficient

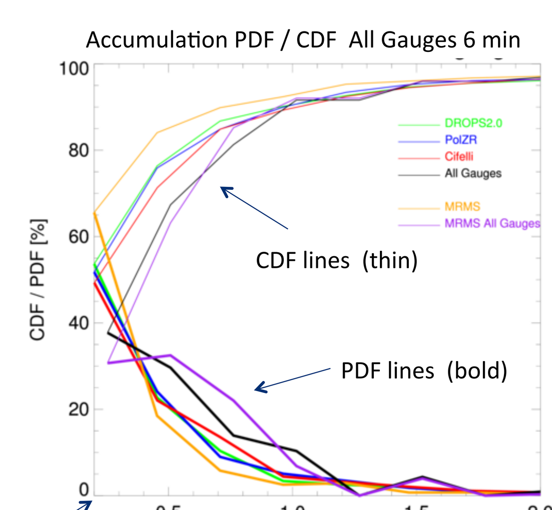
June 2	Bias [%]			MAD [%]			R			Samples		
	6 m	10 m	14 m	6 m	10 m	14 m	6 m	10 m	14 m	6 m	10 m	14m
RR (DROPS2.0)	3.1	2.9	8.8	24.5	21.2	25.1	0.93	0.94	0.93	165	129	109
RP (Bringi)	-9.5	-12.0	-3.4	23.2	22.7	24.1	0.94	0.94	0.93	158	120	105
RC (Cifelli)	16.1	16.9	27.8	27.5	23.6	31.9	0.94	0.96	0.94	178	132	109
MRMS (NOAA)	17.2	20.9	31.0	25.7	30.4	36.0	0.95	0.92	0.92	92	69	58

June 21	Bias [%]			MAD [%]			R			Samples		
	6 m	10 m	14 m	6 m	10 m	14 m	6 m	10 m	14 m	6 m	10 m	14 m
RR (DROPS2.0)	-17.1	-24.3	-28.1	24.0	29.3	32.5	0.93	0.89	0.90	281	247	218
RP (Bringi)	-5.9	-4.7	-5.2	14.7	13.1	11.7	0.97	0.98	0.98	449	329	277
RC (Cifelli)	-10.0	-11.7	-13.5	26.2	27.4	28.0	0.89	0.90	0.91	356	288	235
MRMS (NOAA)	-37.5	-42.8	-39.3	40.8	45.4	44.0	0.77	0.80	0.84	190	190	167

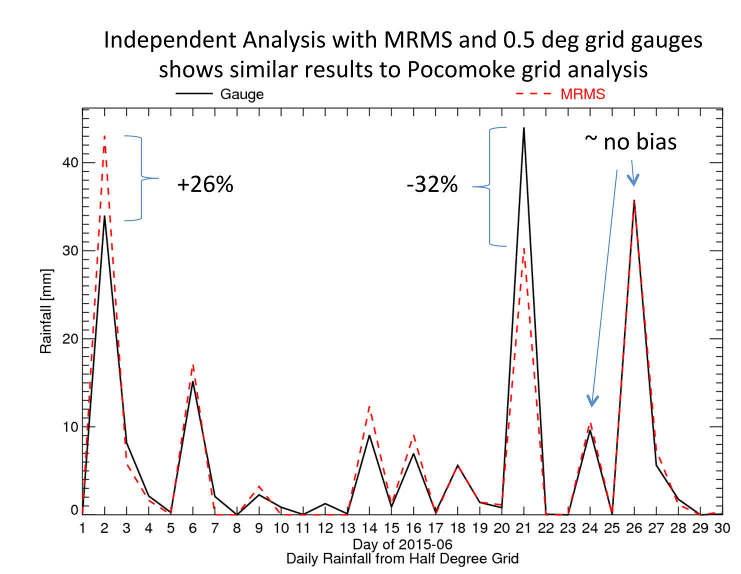
June 24	Bias [%]			MAD [%]			R			Samples		
	6 m	10 m	14 m	6 m	10 m	14 m	6 m	10 m	14 m	6 m	10 m	14 m
RR (DROPS2.0)	-7.4	-6.1	-7.4	11.1	8.1	11.2	0.99	0.99	0.99	25	27	24
RP (Bringi)	-3.5	-6.4	-4.0	8.0	7.7	6.7	0.99	0.99	0.99	27	27	30
RC (Cifelli)	-1.1	-1.8	0.9	7.1	8.9	8.3	0.99	0.99	0.99	26	30	32
MRMS (NOAA)	-2.7	-11.2	-1.2	11.8	22.1	18.0	0.97	0.97	0.99	7	12	14

June 26	Bias [%]			MAD [%]			R			Samples		
	6 m	10 m	14 m	6 m	10 m	14 m	6 m	10 m	14 m	6 m	10 m	14 m
RR (DROPS2.0)	7.6	11.8	24.2	8.8	12.3	25.1	0.99	0.99	0.99	119	128	105
RP (Bringi)	4.5	7.5	12.6	7.2	10.0	14.9	0.99	0.99	0.99	87	106	97
RC (Cifelli)	12.7	23.9	27.9	13.5	23.9	28.4	0.99	0.99	0.99	138	133	116
MRMS (NOAA)	-2.1	-3.1	-1.3	9.3	22.3	21.7	0.99	0.96	0.99	24	65	67

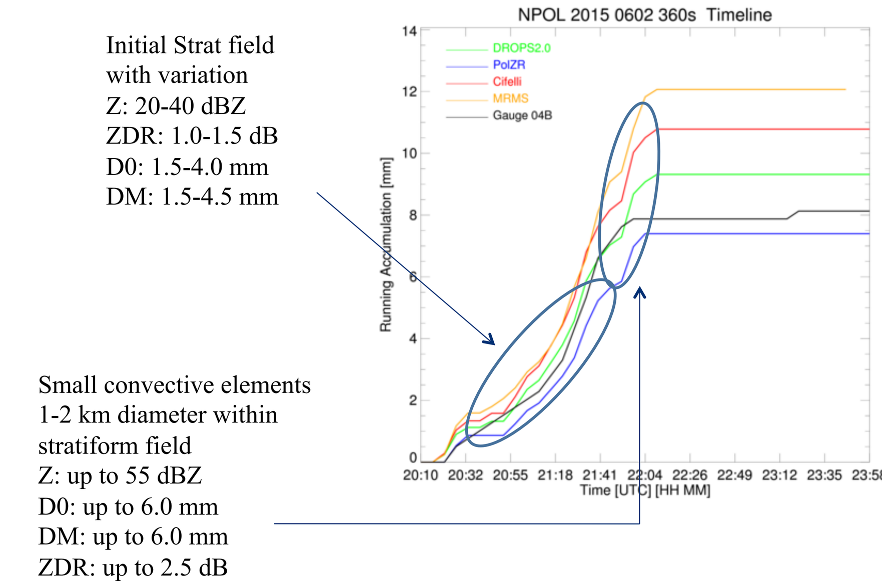
All cases	Bias [%]			MAD [%]			R			Samples		
	6 m	10 m	14 m	6 m	10 m	14 m	6 m	10 m	14 m	6 m	10 m	14 m
RR (DROPS2.0)	-3.4	-3.3	-2.1	14.9	16.3	21.2	0.99	0.99	0.98	559	508	423
RP (Bringi)	-2.4	-2.0	-0.8	12.5	12.9	11.7	0.99	0.99	0.99	668	565	482
RC (Cifelli)	5.1	8.9	12.4	16.5	17.7	20.8	0.99	0.99	0.99	636	536	456
MRMS (NOAA)	-16.8	-21.6	-16.6	24.1	30.4	29.7	0.97	0.91	0.93	277	315	286

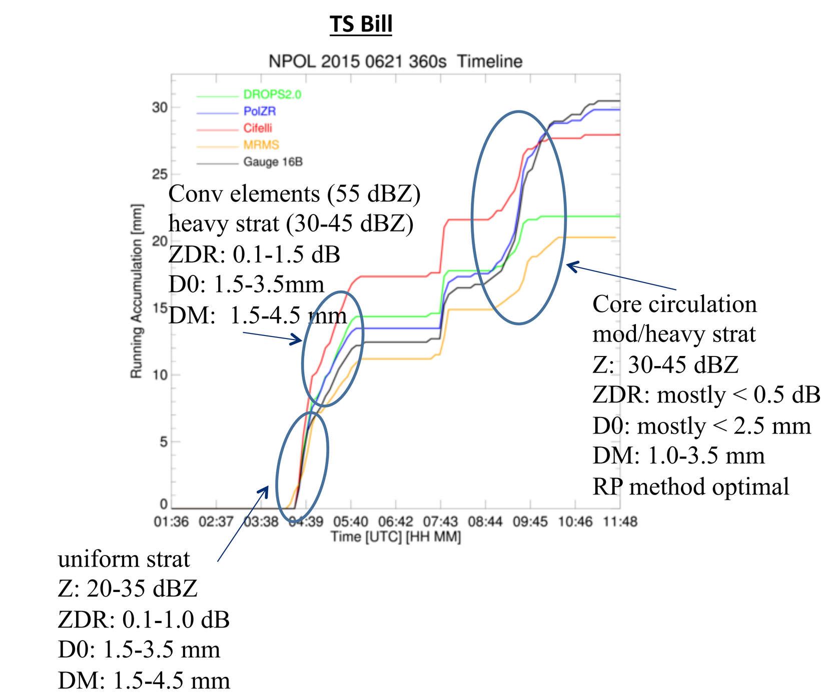


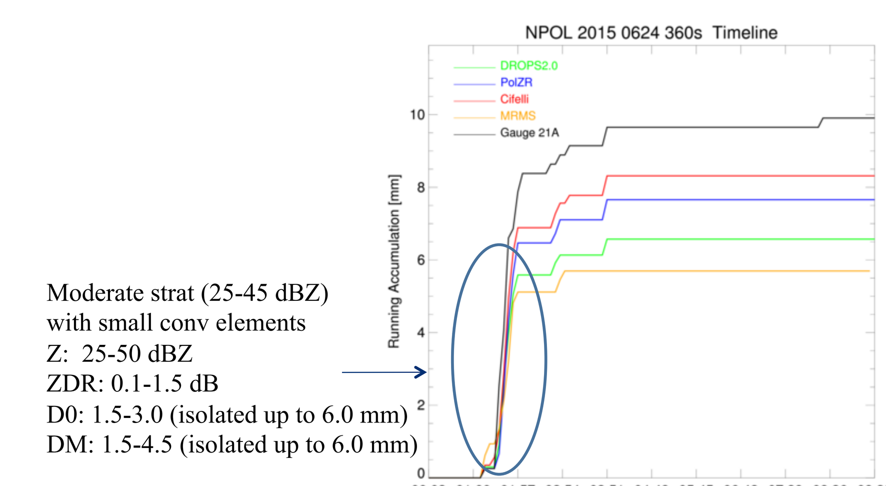
Radar-based accumulations start at 0.20 mm.
Gauge accumulations start at 1 tip (0.254 mm)

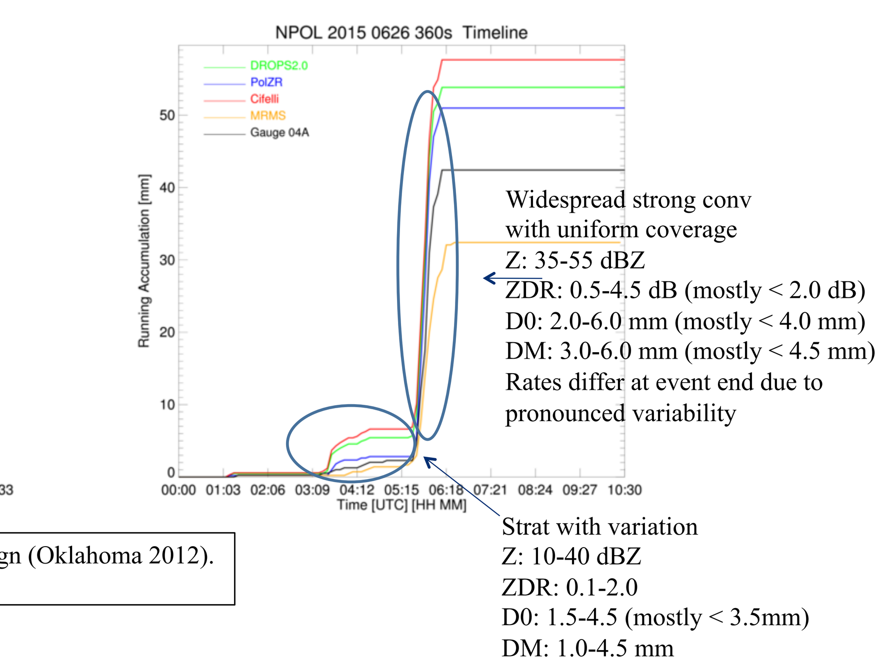


5. Algorithm differences through timeline accumulations



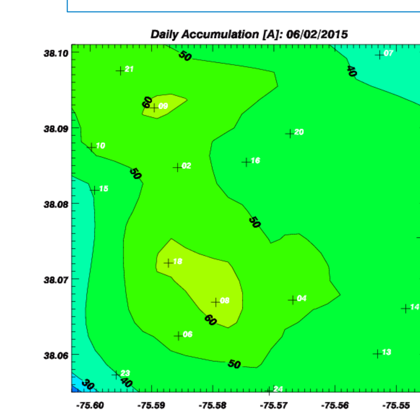




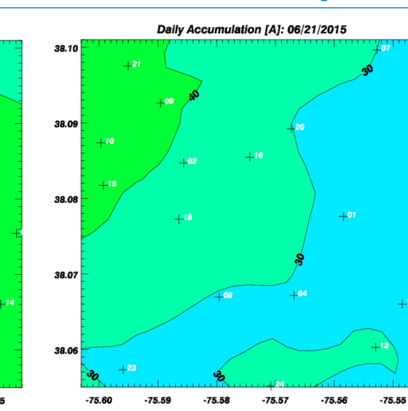


D0 equation derived from 2DVD observations during MC3E field campaign (Oklahoma 2012).
DM equation derived from 2DVD observations at Wallops Flight Facility.

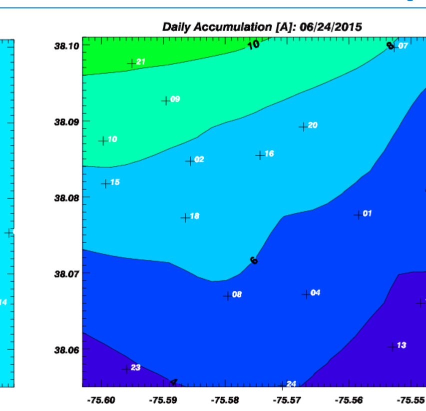
6. Rainfall accumulation variability within a DPR 5km x 5km pixel



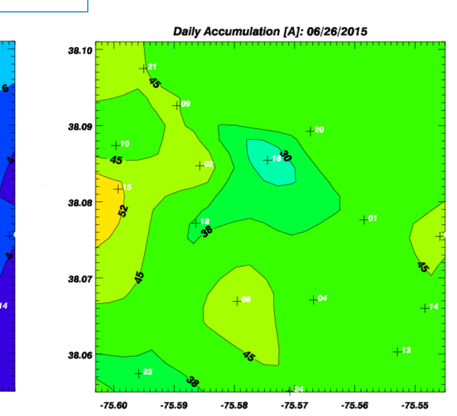
30 mm → 60 mm → 100% Δ



20 mm → 40 mm → 100% Δ



2 mm → 10 mm → 400% Δ



30 mm → 52 mm → 73% Δ

7. Observations

- **Both gauge and radar quality control are critical to comparisons.**
- **The rain rate and accumulation variability over the 25 km^2 grid are significant contributors to error .**
- **There is no clear-cut optimal choice in radar-based estimation algorithms (except for tropical system).**
- **For a modified tropical event, rate estimation using continuously adjusted DSD parameters (Bringi (RP) June 21 event) is clearly optimal compared to the blended polarimetric algorithms and MRMS.**
- The correlation does not show a significant difference between the 6, 10, and 14 minute accumulation periods.
- MAD for polarimetric estimates is 5-10% lower than MRMS with all events combined.
- Within stratiform, increased variability in Z, ZDR and D0 / DM lead to divergence in the polarimetric estimates over time (especially with numerous embedded convective elements).
- A stratiform (or convective) event with minimal variability in Z, ZDR, and D0 / DM lead to similar rates and accumulations from the polarimetric estimates and are highly correlated with gauges.
- The Cifelli (RC) algorithm generally overestimates rates relative to the other polarimetric and MRMS algorithms, but often has the highest correlation with rain gauges.
- The DROPS2.0 (RR) algorithm produces rates lower than RC due to revised default Z-R relation and region-based HID.
- Future work: sensitivity testing of accumulation thresholds from 0.25 mm to 1.0 mm.

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